

# Optical spectroscopy of the candidate luminous white dwarf in the young LMC cluster NGC1818

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## ABSTRACT

An optical spectrum of the Elson et al. (1998) candidate luminous white dwarf in the young LMC cluster NGC1818 shows conclusively that it is not a degenerate star. A model atmosphere fit gives  $T_{eff} \approx 31,500\text{K}$  and  $\log g \approx 4.4$ , typical of a garden-variety main sequence B star. However, if it is a true LMC member then the star is under-luminous by almost three magnitudes. Its position in the cluster colour-magnitude diagram also rules out the possibility that this is an ordinary B star. The luminosity is, however, consistent with a  $\sim 0.5 M_\odot$  post-AGB or post-EHB object, although if it has evolved via single star evolution from a high mass ( $7.6\text{--}9.0 M_\odot$ ) progenitor then we might expect it to have a much higher mass,  $\sim 0.9 M_\odot$ . Alternatively, it has evolved in a close binary. In this case the object offers no implications for the maximum mass for white dwarf progenitors, or the initial-final mass relation. Finally, we suggest that it could in fact be an evolved member of the LMC disk, and merely projected by chance onto NGC1818. Spectroscopically, though, we cannot distinguish between these evolutionary states without higher resolution (echelle) data.

**Key words:** globular clusters: individual: NGC1818 – stars: evolution – white dwarfs

## 1 INTRODUCTION

White dwarfs are believed to be the final endpoint of stellar evolution for all stars  $M \lesssim 8 M_\odot$  (Weidemann 1987). Above some critical mass,  $M_c$ , single stars end their lives by detonating as Type II supernovae, leaving neutron star or black hole remnants. However, there are few observational constraints on  $M_c$ . For example, the earliest type star known with a white dwarf companion is the B5V star  $\gamma$  Pup (HR2875, Vennes, Berghöfer and Christian 1997, Burleigh & Barstow 1998). The degenerate star in this binary system must have evolved from a progenitor with a mass greater than that of its main sequence companion,  $6.0\text{--}6.5 M_\odot$ .

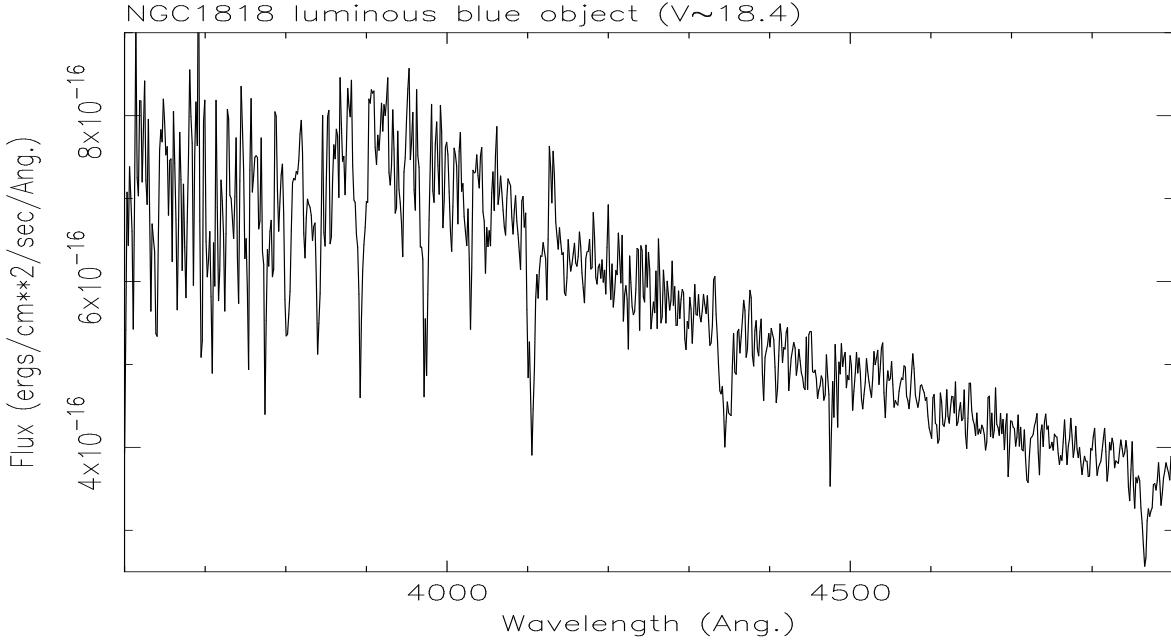
A lower limit on this maximum mass for white dwarf progenitors can also be derived from the study of white dwarfs in young galactic open clusters. Observations of four white dwarfs in the Milky Way cluster NGC2516 by Koester & Reimers (1996) imply the initial stellar mass for forming a white dwarf there is  $\approx 7 M_\odot$ , although Jeffries (1997) used the cluster metallicity to revise and decrease these particular progenitor masses to only  $5\text{--}6 M_\odot$ .

Recently, Elson et al. (1998) announced the discovery

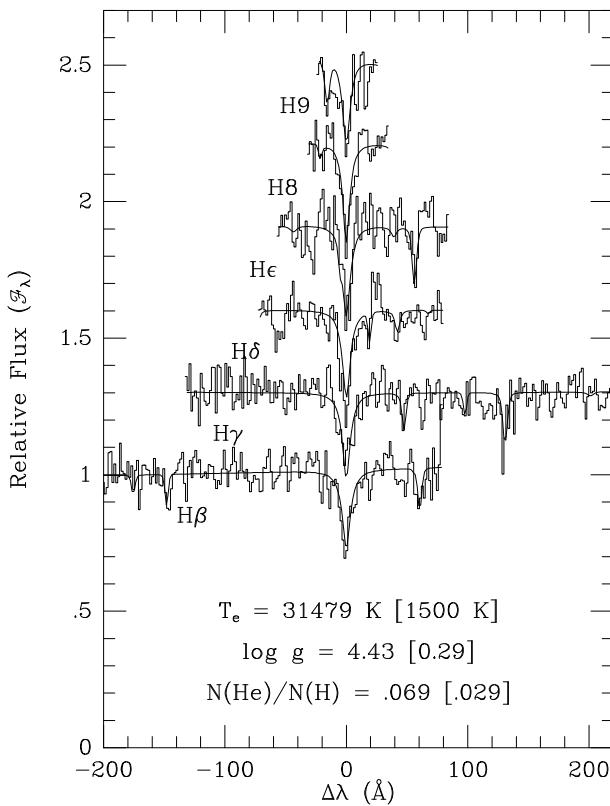
of a candidate luminous white dwarf in the young cluster NGC1818 in the Large Magellanic Cloud (LMC). This cluster has a main sequence turn-off mass of between  $7.6 M_\odot$  and  $9.0 M_\odot$ , depending on whether convective core overshoot is assumed in the models. If this object is indeed a young, hot, massive white dwarf, then the lower limit for the maximum mass for white dwarf progenitors ( $M_c$ ) would be  $\gtrsim 7.6 M_\odot$ .

Elson et al. (1998) used U, V and I colours (obtained with WFPC2 on the Hubble Space Telescope) to identify their white dwarf candidate. However, as pointed out by Liebert (1999), at  $V \approx 18.4$  this object is highly unlikely to be a young, hot white dwarf. At the distance of the LMC,  $\sim 50\text{kpc}$ , the star has an absolute visual magnitude near zero. The most luminous white dwarfs in the Palomar Green Survey, though, are fainter than  $M_v \sim 6$ , and in NGC1818 would be no brighter than  $V \sim 24.5$  (Green, Schmidt and Liebert 1986). In addition, clusters with main sequence masses  $\gtrsim 5.0 M_\odot$  produce massive white dwarfs,  $\gtrsim 0.9 M_\odot$ . By implication these degenerate stars have abnormally small radii, and at the distance of the LMC would appear at  $V \gtrsim 29$ .

In this paper we present an optical spectrum of the El-



**Figure 1.** Optical spectrum of the luminous blue object in NGC1818



**Figure 2.** Model fit to the H Balmer lines

son et al. object, and show conclusively that it is not a white dwarf. We argue that, although spectroscopically it resembles a garden-variety main sequence B star, it appears to be under-luminous by almost three magnitudes. Its position in the cluster HR diagram also excludes this possibility. In-

stead, it may be an object evolving off the extended horizontal branch or, less likely, a post-AGB star. It may even have evolved in a close binary system. However, without high resolution echelle spectroscopy, it is impossible to distinguish between these evolutionary states.

## 2 OPTICAL OBSERVATION

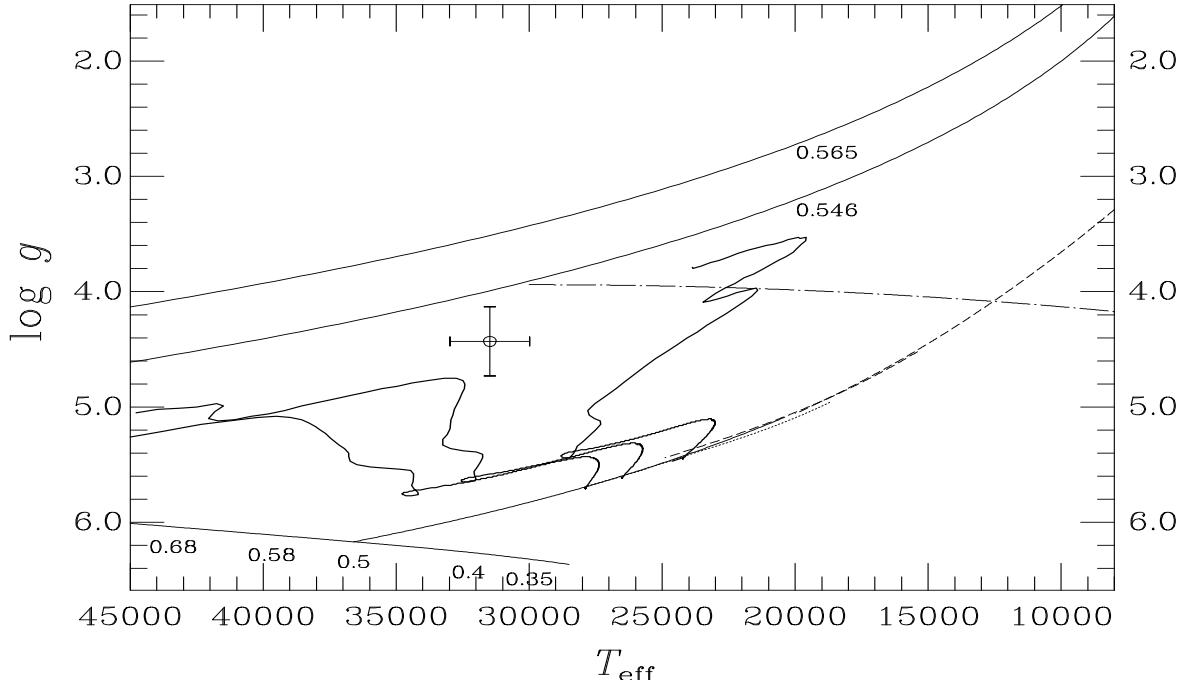
The white dwarf candidate was observed for 1800 secs with the 3.9m Anglo-Australian Telescope (AAT) on 1998 March 5th, using the RGO spectrograph and 600V grating centred at 4200Å. This gave a dispersion of  $\approx 1.55\text{ \AA}$  per pixel on a Tek CCD (running at 170K), equivalent to a resolution of  $\approx 4\text{ \AA}$  (FWHM). A blue/UV flux calibration standard was also observed. These data (Figure 1) were reduced with the Starlink package FIGARO. We note that sky subtraction was difficult, due to the high density of stars in this region, and that the seeing was poor,  $>1.5$  arcseconds.

A nearby comparison star was also observed. The location of this object on the main sequence in the cluster colour-magnitude diagram makes it a highly probable cluster member (see Figure 1 of Elson et al. 1998).

## 3 ANALYSIS

The spectrum is shown in Figure 1. Although the continuum rises fairly steeply towards the blue, indicating that the object is hot, it is immediately obvious that the H Balmer lines are far too narrow for this to be a high gravity object, such as a white dwarf. HeI absorption lines are also visible, for example at 4471Å and 4026Å, along with CaII at 3933.7Å.

A model atmosphere fit to the line profiles (Figure 2) gives  $T_{eff} = 31,500\text{ K} \pm 1500\text{ K}$ ,  $\log g = 4.4 \pm 0.3$ , and  $\text{He/H} = 0.07 \pm 0.03$ . These parameters are consistent with a



**Figure 3.** The position of the NGC1818 object in the  $T_{\text{eff}} - \log g$  plane. Also plotted are evolutionary tracks from Schönberner (1993) for post-AGB stars (solid diagonal lines; core masses labeled in units of  $1 M_{\odot}$ ), the zero-age EHB from Sweigart (1987, dashed line), and the zero-age main sequence (dot-dashed line). Loci showing how objects with a variety of masses evolve away from the EHB are also shown (Caloi 1989).

garden-variety main sequence B star, albeit with a slightly low He abundance which is not very significant.

We note that the difference in radial velocity between this object and the comparison star, measured by cross-correlation, is  $10 \pm 15 \text{ km sec}^{-1}$ . Therefore, it is almost certainly a member of the LMC. However, the expected internal velocity dispersion in the NGC1818 cluster is only  $\sim 1 \text{ km sec}^{-1}$ . Thus we would only be able to test for cluster membership, as opposed to LMC membership, with high dispersion (echelle) spectra.

#### 4 DISCUSSION

The optical spectrum of the luminous blue object in the LMC cluster NGC1818 shows conclusively that it is not a white dwarf. Our model fit shows that it could be a normal main sequence B star,  $T_{\text{eff}} \approx 31,500 \text{ K}$ ,  $\log g \approx 4.4$ .

However, the position of this star in the  $T_{\text{eff}} - \log g$  plane is ambiguous since, in addition to the main sequence, post-asymptotic giant branch (post-AGB) and post-extended horizontal branch (post-EHB) tracks all cross the same area.

Figure 3 shows the  $T_{\text{eff}} - \log g$  plane and the position of the NGC1818 object (marked by the large cross). Also plotted are evolutionary tracks from Schönberner (1993) for post-AGB stars (solid diagonal lines; core masses labelled in units of  $1 M_{\odot}$ ), the zero-age EHB from Sweigart (1987, dashed line), and the zero-age main sequence (dot-dashed line). Loci showing how objects with a variety of masses evolve away from the EHB are also shown (Caloi 1989). Obviously, there are a number of plausible alternative interpre-

tations for the nature of this object. We now discuss each possibility in turn:

A) This is a normal main sequence B star, lying at the distance of NGC1818 and probably a genuine cluster member. Rapid rotation might be expected, with atmospheric abundances characteristic of the cluster. At  $V \approx 18.4$ , though, it would be impossible to determine these parameters without an 8- or 10-m class telescope.

We note, however, that this star appears to be under-luminous by almost three magnitudes for a B star at the distance of the LMC. A  $31,500 \pm 1500 \text{ K}$  zero-age main sequence star in the LMC ( $Z=0.008$ ) has a gravity  $\log g \leq 4.33$  and an absolute magnitude of  $-2.8 \pm -0.4$ , (Schaerer et al. 1993), yet our  $V=18.4$  star has an absolute magnitude of only  $\approx 0$  (assuming a distance of 50 kpc). In addition, the position of this object bluewards of the main sequence in the cluster colour-magnitude diagram (see Figure 1 of Elson et al., 1998) excludes the possibility that this is an ordinary B star. Therefore, we must seriously consider other evolutionary states for this hot object.

B) This is an object on its way to becoming a white dwarf, i.e. a post-AGB star. Figure 3 demonstrates that low-mass (e.g.  $0.546 M_{\odot}$ ) post-AGB tracks run through the same area of the HR diagram as a  $31,500 \text{ K}$ ,  $\log g = 4.4$  B star. However, Liebert (1999) argues that this star is unlikely to be a post-AGB cluster member. As pointed out in the introduction to this paper, we would expect its mass to be high ( $\gtrsim 0.9 M_{\odot}$ ) compared to typical, older stellar remnants. A high mass post-AGB star, though, would have a luminosity inconsistent with the NGC1818 object. For example, a  $0.855 M_{\odot}$  post-AGB star has a luminosity  $\log L/L_{\odot} \sim 4.3$  (Vassiliadis

& Wood 1994), yet our object has a luminosity of only  $\log L/L_\odot \sim 3.0$ .

C) This is a post-EHB cluster member. The timescale for evolution in this phase certainly makes it more likely that this is a post-EHB object rather than a post-AGB star. Schönberner (1983) gives the timescale for post-AGB cooling in this region as  $10^3$ – $10^4$  years, while that for HB evolution through this region is  $10^6$ – $10^7$  years (Castellani et al. 1994). The surface gravity is as expected for a post-EHB object, although it is too low for an object on the zero-age EHB (at this temperature, see Figure 3). The luminosity is also consistent with a  $\sim 0.5 M_\odot$  post-EHB object. However, as with the post-AGB scenario, the formation of such an object via single star evolution may be unlikely, since the star would have had to lose around  $6 M_\odot$  of envelope as it ignited helium. Horizontal branch stars, like post-AGB stars, are slow rotators, so high resolution spectra would help to distinguish its evolutionary status. If it is a post-EHB star, then during its time at high gravity prior to He-exhaustion it would have altered its abundances through diffusion. Again, though, there is no way to tell without much higher resolution data.

D) Liebert (1999) offers one other speculative interpretation. Perhaps this object has been formed through close binary evolution, such that the white dwarf progenitor has lost its envelope (through mass transfer to the companion) before the mass of the core has reached the level required for helium ignition. This undermassive progenitor core would evolve on a post-RGB track that is parallel to, but at a much lower luminosity than, the post-AGB track for any higher mass core produced by single star evolution. Such systems have been observed, for example, in the centres of planetary nebulae (Napiwotzki 1999). In this case the object is indeed becoming a white dwarf, but because it has been evolving via binary evolution it offers no implications for the upper mass limit for white dwarf progenitors.

However, if it is in a close binary then it should be suffering large radial velocity variations and, statistically, we would expect to see it near velocity extrema. Since the velocity appears to be the same as the LMC velocity, we might conclude that close binary evolution is a low-probability alternative. Again, though, our current data may be too low in resolution to draw such a conclusion.

E) Finally, we suggest that this object could be a post-EHB star, but that it is not a member of the NGC1818 cluster. Instead, it lies in the disk of the LMC and simply appears projected by chance onto NGC1818. Although this may seem statistically unlikely, we note that considerable star formation has occurred in the LMC over the last  $\sim 2$  Gyr and thus the object need not have evolved from a high mass progenitor. It also need not have formed through binary evolution. However, no convincing horizontal branch has been observed in the vicinity of NGC1818 (see Fig. 4 of Hunter et al. 1997), and thus the existence of a post-EHB star in this region is improbable. Once again, though, the test of this option is an echelle spectrum with much improved velocity resolution.

A comparison can be drawn between this object and the  $V \approx 14.5$  hot blue star PG 0832+676 (Hambly et al. 1996). In low resolution spectra this object also closely resembles

a young B-type star. However, high resolution observations demonstrate that it is extremely sharp lined ( $v \sin i \sim 1$  km sec. $^{-1}$ ), has a low projected rotational velocity, and that although the abundances of helium, nitrogen and oxygen are near normal, there is a systematic depletion of  $\sim 0.4$  dex in the abundances of other elements. Therefore, Hambly et al. concluded that the object is most likely an old, evolved star, either in the post-AGB phase or more probably evolving off the EHB.

High resolution spectroscopy is similarly now required for the NGC1818 object, for a detailed abundance analysis, a rotational velocity determination, and an accurate radial velocity determination, in order to distinguish between the various possible evolutionary states. However, at  $V=18.4$  this will only be possible with the new generation of southern hemisphere 8–10-m class telescopes, such as the VLT or Gemini.

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## REFERENCES

- Bergeron P., Saffer R.A., Liebert J., 1992, ApJ, 394, 228
- Burleigh M.R., Barstow M.A., 1998, MNRAS, 295, L15
- Caloi V., 1989, A&A, 221, 27
- Castellani M., Castellani V., Pulone L., Tornambe A., 1994, A&A, 282, 771
- Elson R.A., Sigurdsson S., Hurley J., Davies M.B., Gilmore G.F., 1998, ApJ, 499, L53
- Green R.F., Schmidt M., Liebert J., 1986, ApJS, 61, 305
- Hambly N.C., et al., 1996, ApJ, 466, 1018
- Hunter D.A., Light R.M., Holtzman J.A., Lynds R., O’Neil E.J., Grillmair C.J., 1997, ApJ, 478, 124
- Jeffries R.D., 1997, MNRAS, 288, 585
- Koester D., Reimers D., 1996, A&A, 313, 810
- Liebert J., 1999, ApJ, 514, L25
- Napiwotzki R., 1999, A&A, *in press*
- Schaerer D., Meynet G., Maeder A., Schaller G., 1993, A&AS, 98, 523
- Schönberner D., 1983, ApJ, 272, 708
- Schönberner D., 1993, in IAU Symp. 155, Planetary Nebulae, ed. R. Weinberger & A. Acker, Kluwer, Dordrecht, 415
- Sweigart A.V., 1987, ApJS, 65, 95
- Vassiliadis E. & Wood P.R., 1994, ApJS, 92, 125
- Vennes S., Berghöfer T., Christian D., 1997, ApJ, 491, L85
- Weidemann V., 1987, A&A, 188, 74